[Fourth Edition.]

AMENDED SPECIFICATION.

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The Amendments are shown in erased and italic type.

PATENT SPECIFICATION

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COMPLETE SPECIFICATION (AMENDED).

Improvements in Speech Frequency Translating Systems.

(Communicated by Western Electric Company, Incorporated, a corporation of the State of New York, having a principal place of business at 463, West Street, New York, State of New York, United States of America).

We, Western Electric Company, Limited, of Connaught House, Aldwych, London, W.C. 2, England, a British corporation, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to speech frequency translating systems in which acoustic devices are employed such as the loud speaking horns or other air vibrating means for example in connection with phonographs, loud speaking telephone receivers and the like.

The object of the present invention is to improve the transmission characteristic of loud speaking devices and the like.

The transmission characteristic has a curve obtained by applying input frequency against output intensity. It is well known that hitherto in loud speaking devices this curve shows a peak of about 1000 cycles due to the resonant frequency of a vibrating member; thus, the intensity of output sound is not uniform, certain frequencies being amplified more than others.

It will be obvious that if it were possible to make this curve substantially flat over a suitable range of frequencies the reproduction of sound issuing from the horn would be more natural. Hitherto various methods have been proposed for flattening out the peak, but these proposed methods have not been successful as they have either contemplated tuning the vibration absorbing device to the undesired frequency such as the natural frequency of the vibrating member or else providing damping means for flattening the amplitude peak. These methods have resulted in attenuating the desired frequencies and thus the total efficiency has been considerably lowered.

This invention provides therefore a method of improving the transmission characteristic of loud speaking devices which consists in arranging an air chamber between a vibrating member and the input end of a horn and adjusting the dimensions of the chamber so that the opposition to mechanical vibratory energy flow, usually termed the mechanical impedance, due to the combined effect of the mass of the vibrating member and the elasticity of the air in the chamber is of the same order of magnitude as the opposition to mechanical energy flow of the air in the horn.

In the particular form of this invention an accurate balancing of the various elements is a considerable aid in obtaining high quality reproduction, since

reflection losses are thereby made negligible or eliminated and the transmission frequency characteristic is enormously improved. Such an equalisation of the mechanical impedance of the receiver and that of the horn is of special utility when the receiver and horn are combined with an electric system wherein an accurate matching of impedances has been made so that each electric device of the system works into its own impedance for the frequency range to be transmitted, especially in the cases where energy rather than voltage is being transferred. This invention, therefore, proposes, in one aspect, a telephone transmitter working into an amplifier of one or more stages, the output of the amplifier being coupled to a loud speaking receiver and horn. The amplifier circuits are so designed that the telephone transmitter works into its own impedance and the external impedance between the output electrodes of the amplifier is matched with the internal impedance. If now the mechanical impedance of the loud speaking receiver is equal to the mechanical impedance of the horn, the resulting system is obviously of wide utility for the accurate production of sound waves for any desired purpose.

The arrangement hereinafter described centres attention mainly upon the driving mechanism of the horn which may, for example, be a telephone receiver. For the purpose of this specification the horn will be assumed as having a constant impedance over the essential speech range equal to the impedance of a tube of infinite length and having a diameter equal to the diameter of the small end of the horn.

The mechanical impedance of a telephone receiver is a quantity which varies greatly with the size and arrangement of the vibrating structure. The one necessary common element in all vibratory structures is a mass which is acted on by a mechanical force, electrically produced for example. The mechanical impedance of a mass itself cannot, however, be matched over a wide frequency range with the mechanical resistance of the horn, because that is the same in the electric field as attempting to make an inductance have the same impedance as a pure resistance, which of course, cannot be done for a range of frequencies. In accordance with this invention, however, it is proposed to associate the mass of the moving element with such elasticity or combination of elasticities that the impedance of the resulting combination approximates a pure mechanical resistance over a wide frequency range, which, of course, can be made to have a value equal to the mechanical resistance of the horn. Reflection losses are thereby prevented and the frequency transmission characteristic from the receiver to the open air at the large end of the horn is considerably improved over the essential speech range. If, now, such a mechanically matched system is employed for translating into sound waves electric waves of an electric system in which there is a matching of electric impedances from one device to another, it follows that the combined system will be one of high quality.

Another viewpoint which can be taken of this invention is that the combined receiver and horn constitutes a mechanical transmission line having masses and elasticities of predetermined values. A mechanical transmission line can be compared to an electric transmission line since an inductance corresponds to a mass, a capacity to the reciprocal of the elasticity, an electric resistance to mechanical resistance. The impedance of a mechanical transmission line comprising a large or infinite number of recurring sections, each comprising a series mass and a shunt elasticity is given by the following equation for frequencies substantially below the critical frequency:

$$Z_0 = \frac{1}{\pi}\sqrt{\frac{S}{M}}, \sqrt{SM}$$

where Z_0 is the impedance, M the mass per section and S the elasticity per section.

If now we assume a plunger operated by an elastic reed fastened to an armature, the plunger being located in the small end of a horn, the resulting mechanical transmission line constitutes in its first section a series mass (the mass of the armature), and an elasticity (the elasticity of the reed). This elasticity as has been explained in "Frequency Filters" by E. K. Sandeman, "Wireless World", pages 643 and 685, Vol. 14, is in effect similar to an electric condenser in shunt and may therefore be referred to as shunt elasticity.

The second section comprises a series mass (the mass of the plunger), and special means must be provided for obtaining a shunt elasticity for the second section. This may be done by providing an air chamber of suitable size around the small end of the horn to have this desired elasticity for the second section. If now these two sections are coupled to a mechanical network having a mechanical impedance equal to the mechanical impedance of a transmission line

composed of an infinite number of full sections, the impedance of the combined network and the two mentioned sections will closely approximate the impedance of a line of an infinite number of such sections. This mechanical terminating network should preferably be coupled to a section terminated at mid-shunt, which would be one having twice the elasticity of a full section. Such a terminating network may comprise a horn which has a substantially constant impedance for the frequency range under consideration. The first section, that is the armature and reed, may constitute a section terminating at mid-series of mid-shunt since such terminations are sometimes preferable from a constant impedance standpoint to the full series or full shunt termination. By mid-series termination is meant that the mass of the armature is one half the mass of the plunger and by mid-shunt termination is meant that the elasticity of the reed is twice that of the air chamber. Other fractional terminations may also be desirable in some cases. The above description also applies to the case where only one section is provided in addition to the horn, which would be the case if the reed and armature were omitted.

Referring to the drawings, Fig. 1 represents a telephone receiver of an elementary type. Fig. 2 illustrates the mechanical impedance diagram of the system of Fig. 1. Fig. 3 illustrates curves on a logarithmic scale showing the frequency characteristic of the system of Fig. 1. Fig. 4 illustrates an electric loaded line. Fig. 5 represents the frequency transmission characteristic of such a loaded line drawn on a logarithmic scale. Fig. 6 illustrates how the system of Fig. 1 may be modified to embody the present invention. Fig. 7 is a mechanical impedance diagram of the system of Fig. 6. Fig. 8 illustrates by curves on a logarithmic scale the transmission characteristic of the system of Fig. 6. Fig. 9 is a modification of the system of Fig. 6 in which a diaphragm is employed. Fig. 10 is a mechanical impedance diagram of the system of Fig. 8. Fig. 11 represents by curves on a logarithmic scale the frequency characteristic of the system of Fig. 8. Fig. 12 is a modification of this invention in which a pivoted armature is employed. Fig. 13 is a mechanical impedance diagram of the system of Fig. 12. Fig. 14 illustrates a system of this invention employing a pivoted armature and a diaphragm. Fig. 15 illustrates the transmission characteristic of the system of Fig. 14, and Fig. 16 illustrates this invention embodied in a loud speaking telephone system.

Fig. 1 illustrates a combined telephone receiver and horn of an elementary type, the receiver comprising a plunger 20 adapted to work into the small end of a horn 21 and suitably carrying an induction coil 22. This induction coil 22 surrounds one end of a permanent magnet 23. In the absence of alternating currents in the line 24, the plunger 20 is not biassed to any one position since it is assumed to be of non-magnetic material and will be oscillated only when a magnetic field is set up by currents in coil 22 which opposes or aids the permanent magnetic field of the magnet 23. Such a receiver has no elasticity since the plunger 20 is assumed to be of stiff material and since no elastic means, such as a spring, is employed to bias the plunger to one position or the other. The mechanical impedance of such a receiver as shown in Fig. 1, therefore, consists simply of a mass working into the mechanical impedance of the horn which will be assumed to be of constant impedance with frequency, and, therefore, a pure mechanical resistance for the range of frequencies under consideration.

The mechanical impedance diagram of such a system as that shown in Fig. 1 may, therefore, be represented as in Fig. 2 in which the generator 25 represents a driving force, inductance 26 represents the mass of the plunger and the resistance 27 represents the resistance of the horn. With the inductance 26 and resistance 27 connected in series across the terminals of the generator 25, it follows that the impedance into which the generator works varies with the frequency as shown in Fig. 3. If the ~~mass~~ *reactance* of the plunger *at* 6000 *cycles* is equal to *twice* the resistance of the horn the frequency transmission characteristic is similar to that of curve 28, while if the ~~mass~~ *reactance* is equal to ~~twice~~ the resistance of the horn the curve is similar to curve 29, and if the ~~mass~~ *reactance* is equal to ~~four times~~ *one half* the resistance of the horn the curve is similar to curve 30. These curves are plotted with various frequency values as abscissæ and with energy output to the horn as ordinates assuming that a constant force is acting on the receiver mass. The failure of these curves to approximate a straight line parallel to the horizontal axis is due to the failure of the matching of the mechanical impedance of the receiver to that of the horn for the frequencies involved.

It is well known in the electric art, however, that if an artificial network is

built up of a plurality of sections, each section comprising a series inductance and a shunt capacity, that the capacities and inductances may be made of such value that the resulting network has a substantially constant impedance over a wide frequency range, which, for example, may be made the range of importance in speech. Since in the mechanical art masses are the equivalents of inductances and the reciprocal of elasticity is the equivalent of capacity, it follows that if the coupling of the receiver to the horn is made to approximate a mechanical transmission line consisting of a plurality of series inductances and shunt elasticities, that the coupling of the receiver to the horn may be designed to provide for the desired matching of impedances.

Fig. 4 represents the electrical equivalent of such a mechanical transmission line in which 31 represents a generator or other source of force, elements 32, 33, 34 and 35 are series inductances or masses, and elements 36, 37 and 38 are shunt capacities or elasticities. As is well known in the electric art such an electric circuit if *effectively infinite in length or* terminated at mid-series *with its surge impedance* will have an impedance characteristic substantially constant with frequency over a wide range of frequencies—that is, it will have nearly constant value up to a frequency of about $^{8}/_{10}$ the critical frequency. Curve 39 of Fig. 5 illustrates the impedance characteristic which may be obtained by a mechanical transmission line containing masses and elasticity coupled to a driving force in the manner illustrated in Fig. 4. As shown in the drawing, curve 39 is approximately a straight line parallel to the horizontal axis until a frequency approximately $^{8}/_{10}$ of the critical frequency has been reached.

Fig. 6 illustrates the manner in which the plunger receiver of Fig. 1 may be modified to approximate the mechanical transmission line of Fig. 4 by providing a shunt elasticity of such a value that taken in connection with the mass of the plunger, the combined ~~mechanical~~ *surge* impedance is substantially constant with the frequency and equal to the impedance of the associated horn. The permanent magnet 40 is shown surrounded by a coil 41 which is supported by the plunger 42. Between the plunger and the small end 43 of the horn 44 is a small air chamber 45 into which a portion of the air compressed by the plunger can escape when the plunger is moved away from the magnet 40, and from which additional air may come when the plunger 42 is moved in the opposite direction. This additional air chamber 45 therefore serves as a shunt elasticity, the same as a shunt capacity of an electric system and the volume of this air chamber may be readily adjusted to give the elasticity desired for any particular mass of the plunger, and for the particular horn.

Fig. 7 illustrates the mechanical transmission characteristic of the system of Fig. 6 in which element 47 represents the driving force and connected in circuit with the driving force is an inductance or mass 48 which corresponds to the mass of plunger 42, a shunt capacity or elasticity 49 corresponding in value to the elasticity of the air chamber 45, and an electrical pure resistance 50 corresponding to the mechanical pure resistance of the horn 44. This figure therefore shows the driving force 47 working into a resistance 50 by a coupling device comprising a series inductance or mass and a shunt capacity or elasticity.

The curves 51 of Fig. 8 shows, for the system of Fig. 6, that below $^{8}/_{10}$ths of the critical frequency the impedance match is very good as the horn impedance equals the impedance of an artificial line built up of receiver sections comprising a series mass or inductance, and a shunt capacity or elasticity. Curve 52 illustrates the character of transmission obtained if the surge impedance of the mechanical transmission line is twice the horn impedance, and curve 53 shows the impedance character for the case where the surge impedance is five times the horn impedance. On the other hand, curves 54 and 55 show the character of the impedance of the system in case the horn impedance is twice the surge impedance and five times the surge impedance respectively. These curves, of course, show that the best frequency transmission is obtained by having the surge impedance of the mechanical transmission line equal to the horn impedance. If the horn impedance is less than the surge impedance then the low frequencies are emphasized and the high frequencies are reduced, while if the horn impedance is greater the effects are reversed. It may be noted that the curves are drawn down only to 100 cycles. Below 100 cycles the impedance of the horn assumed does not approximate a pure resistance and will not transmit and radiate sound as satisfactorily as for high frequencies. It is understood, however, that a horn may be employed which will be accurate for any desired minimum frequency providing the horn may be made sufficiently long and have the proper mouth opening.

The system described in Fig. 6 is one in which the movable element is a plunger having no elasticity. In some cases, however, it is desirable to employ a receiver having a movable element such as a diaphragm which in addition to possessing mass also possesses elasticity to a desired degree.

Fig. 9 illustrates a receiver element comprising a diaphragm 56 working into the small end of a horn 57. The diaphragm may be suitably vibrated by an electromagnet 60 comprising a coil 58 connected to an incoming line 59. Similarly to Fig. 6 the small end of the horn 57 is surrounded by an air chamber 61 to provide the necessary shunt elasticity. Due to the fact that the elasticity of the diaphragm acts as a series elasticity, the mechanical impedance diagram for Fig. 9 is that shown in Fig. 10 in which the driving force 62 has connected in circuit therewith a mass or inductance 63 corresponding to the mass of the diaphragm, a series capacity or elasticity 64 corresponding to the elasticity of the diaphragm, a shunt capacity or elasticity 65 corresponding to the elasticity of the air chamber 61 and a pure resistance 66 corresponding to the resistance of the horn 57 for frequencies above 100 cycles. The inclusion of the series elasticity 64 is a departure from the ideal mechanical transmission line of Fig. 4 which has only shunt elasticity or capacity. The curve shown in Fig. 11, however shows that by the proper choosing of the mass of the diaphragm and size of the air chamber 61 that the beneficial results obtained by the matching of mechanical impedance may still be retained in spite of the presence of the series elasticity. Curve 67 of Fig. 11 represents the type of frequency transmission characteristic obtained for the system of Fig. 9 when the surge impedance of the mechanical transmission line equals the impedance of the horn. The fact that the curve departs somewhat from a straight line parallel to the horizontal axis is due to the presence of the series elasticity corresponding to the elasticity of the diaphragm. The curves 68 and 69 shown for illustrative purposes to indicate the character of the impedance when the surge impedance of the mechanical line is respectively twice and five times the impedance of the horn, while curves 70 and 71 show the character of the response obtained when the horn impedance is respective twice and five times the surge impedance. The character of the response obtained as shown by curve 67 is far superior to the character of the ~~impedance~~ *response* obtained with the mechanical transmission line arranged in other possible impedance relations.

Another possible addition to the receiver system of Fig. 1 is to have the plunger driven by a pivoted member possessing both elasticity and mass. A possible arrangement is shown in Fig. 12 in which the plunger 72 is shown connected to one end of a pivoted armature 73 having a reed 86, such as is employed in standard telephone receivers. This reed 86 may be suitably driven in any well known manner to cause the vibration of plunger 72 in accordance with alternating currents present in an electric line associated therewith. The plunger 72 is shown working into the small end of a horn 74, and as in Fig. 9 the small end is surrounded by an air chamber 75 in order to provide a shunt elasticity which will combine with the mass of the plunger 72 to give the desired impedance.

The mechanical transmission diagram of the coupling arrangement of Fig. 12 is shown in Fig. 13 in which the driving force 98 is connected in circuit with a series inductance or mass 76 corresponding to the mass of the pivoted armature 73, a shunt capacity or elasticity 77 corresponding to the elasticity of reed 86, a series mass or inductance 78 corresponding to the mass of the plunger 72, a shunt capacity or elasticity 79 corresponding to the elasticity of the air chamber 75, and a resistance 80 corresponding to the resistance to the horn 74. The mechanical coupling system of Fig. 12 therefore consists of two sections of a mechanical lumped transmission line such as shown in Fig. 4, since two sections are shown each comprising a series inductance or mass and a shunt capacity or elasticity. The series elasticity discussed in connection with Fig. 9 is not present in the system of Fig. 12 since a plunger necessitating no elasticity is employed for impressing sound waves upon the air contained in the horn. The character of the response obtained by the system of Fig. 12 therefore closely approximates that illustrated by curves 51 of Fig. 8 when the surge impedance of the mechanical line, comprising the two above mentioned sections, is made the equal to the horn impedance.

In the case of the arrangement of Fig. 12 the vibratory mass of the armature 73 should preferably be one-half of the plunger or piston 72 and the reed 86 should have an elasticity one-half that between the piston and the horn. This provides a mechanical transmission line which terminates mid-series at one end

and mid-shunt at the other end, since the series mass of the first section is one-half the series mass of the second section and the elasticity of the last section is ~~one-half~~ *twice* the elasticity of a whole section. The horn of course is made to have an impedance equal to that of an infinite number of full sections.

If, as is sometimes the case, the piston or diaphragm is larger than the small end of the horn, a transformer problem is added to those already considered. Fig. 14 illustrates such an arrangement in which the plunger 81 is shown to be working into a horn 82, the small end of which has a diameter considerably less than the diameter of the plunger. As in the previous case, a suitable air chamber 83 is employed for coupling the plunger to the small end of the horn 82. The plunger 81 is driven in a suitable manner by a pivoted armature 84 which possesses mass and a reed 85 having elasticity being connected between the armature and plunger. A transformer action is present in the system of Fig. 14 since the plunger 81 and the horn 82 are of different areas, and both work into the same chamber. For free transfer of energy through this air chamber 83, the squared force acting on the plunger divided by the surge impedance of its lumped mechanical transmission line should equal the squared force acting into the horn divided by the horn impedance. If the air chamber 83 is of small diameter it is sufficiently accurate for the purpose of this invention to assume the pressure to be the same throughout the chamber and that the piston and horn forces are proportional to their areas. The condition for free energy transfer may then be written

$$\frac{A_1^2}{Z_1}=\frac{A_2^2}{Z_2}$$

where A_1 is the piston area, Z_1 the surge impedance of the equivalent mechanical line, A_2 the area of the small end of the horn and Z_2 the impedance of the horn.

The reason for making the diaphragm larger than the horn opening is the difficulty of otherwise matching impedances because of the high specific density of the diaphragm material compared with the density of air. This will be shown plainly by the calculation of parts and chambers to match into a representative horn.

The following are the steps in matching a receiver of the balanced armature type to a horn, such as in the system of Fig. 12. The first step is the calculation of the horn impedance. If the horn is assumed to have a substantially logarithmic outline with a mouth diameter of 22" to have a small end diameter of .690" and to be 38" in length, the impedance over the usual frequency range will then be

$$\text{(II) } Z_2=43\ A_2,$$

where Z_2 is the impedance of the horn, and A_2 is the area of the small end of the horn, which in the case assumed is 2.41 sq. centimeters. With these values the impedance will be equal to 104 dynes per centimeter per second *of air displacement.*

The second step is the calculation of the piston mass. We will assume a piston with an area of 17.8 sq. centimeters. Rearranging the equation (1) above

$$Z_1=\frac{A_1^2}{A_2^2}\times Z_2$$

and substituting the values given, the proper value of Z_1 for the piston system comes out equal to 5670 dynes per centimeter per second.

The equation for the surge impedance of the mechanical line in terms of the critical frequency and mass as shown in Fig. 12 is

$$\text{(III) } Z_1=\pi f_c M$$

and solving for mass $M=\frac{5670}{\pi f_c}$. It has been found that the smallest value of f_c consistent with high speech quality is approximately 5000 cycles, and if a value of 6000 cycles is used and substituted for f_c in the above equation M, the mass will come out to be .296 grams. In the equations herein given M is the total mass for a full section and S is the elasticity for a full section.

The next step is an examination of this value of M to ascertain if a piston of such a mass can be constructed. Assuming a density of the piston material of unity, the thickness would be

$$f=\frac{M}{A_1}=\frac{.296}{17.8}=.0166\text{ cm.}=.0065\text{ inches.}$$

This corresponds to a thickness for aluminium of .0024" which is an almost impossible thickness for the diameter of $1^7/_8$". From the inspection of the above equations it follows that to increase the thickness of the piston, either the piston area must be increased or the horn opening must be reduced. It is more practical in this case to reduce the horn opening. If the area of the horn opening is reduced by $^1/_2$ the piston mass will be doubled, and if the horn opening is reduced by $^3/_4$ the piston mass is multiplied by 4. Assuming the area of the small end of the horn to be decreased to

$^1/_4$ of the value given above, A_1 will then equal .60 sq. centimeters, M_1 will equal 1.184 grams, and T will equal .066 centimeters for a specific density of unity.

The fourth step is the calculation of the thickness of the air chamber required between the piston and the horn. The elasticity which this chamber should have should be twice that calculated from the formula

$$\text{(IV)}\ f_c = \frac{1}{\pi}\sqrt{S/\cancel{M}\ M}$$

where S and M are respectively the elasticity and mass shown in Figs. 3 and 4. This is because we desired to have a mid-shunt termination at the horn. As discussed under Figs. 4 and 5 a network composed of series mass and shunt elasticity should be terminated by a mid-shunt connection at the horn if the frequency ~~transmission~~ *impedance characteristic* desired is such as shown by the curve of Fig. 5. In order to calculate the thickness of the air chamber required, we will therefore use for the elasticity (S^1) a value equal to twice that of the reed between the piston and the armature since we desire to have the piston and the associated elasticity terminated by a mid-shunt section.

Substituting the values given above equation (IV) then becomes

$$S^1 = 1.18 \times 2\,\pi^2 \times 6000^2$$

which gives for S^1 the value of 8.4×10^8 dynes per centimeter.

The required elasticity per unit area is:

$$S^1 = \frac{8.4 \times 10^8}{17.8} = 47.2 \times 10^6.$$

The elasticity of air per square centimeter per centimeter length is 1.5×10^6 dynes; hence the required air chamber depth is

$$d = \frac{1.5 \times 10^6}{47.2 \times 10^6} = 0.317 \text{ cm.} = .013''.$$

The particular value for the depth of the air chamber as just calculated is so small that in general it will be found desirable to curve the sound path into the horn in order to prevent the formation of eddies due to sharp changes in the path of the air.

The next step is the calculation of the proper coupling of the armature to the piston or diaphragm. The moment of inertia of the armature may be assumed as $I = .9$ gr. cm.^{2}. For mid-series termination, which is perhaps the most desirable, the mass of the armature should be one-half that of the piston, or .592 grams. The point of coupling the armature to the piston, that is the distance L from the armature axis may be found from the equation:

$$\text{(VI)}\ \frac{M}{2} = \frac{I}{L^2}.$$

Solving and substituting the values given above

$$L = \sqrt{\frac{2\,I}{M}} = \frac{1.8}{1.184} = 1.52 \text{ cm.} = .589''.$$

Between the coupling point at .598″ and one-half the magnet length .375″, there is a distance of .223″ which may be used for a reed coupling spring. This spring should have the same elasticity as calculated under step 4, namely $S = 4.2 \times 10^8$.

The elasticity, s, of a reed is given by the equation $s = \frac{3\,q\,I}{L_1^3} = \frac{3\,q\,bd^3}{12L_1^3}$ as may be verified by the equation given on page 289 of Volume I of Lord Rayleigh's "Theory of Sound". In this equation, L_1 is the length in centimeters; q is Young's modulus, which is 20.9×10^{11} dynes per sq. cm., for steel (silicon); $I = \frac{bd^3}{12}$, which is the moment of inertia of a cross sectional about a neutral axis, b is the width of the reed, and d, the thickness of the reed.

If we assume that the width of the reed is .125″ = .318 cm., then s will be found by the above equation to be $1.50 \times 10^{14} d^3$, or that d is equal to .014 cm.

The above specific calculations illustrate the manner in which the various component parts of the system of Fig. 14 may be arranged in order to obtain the beneficial results produced by this invention. As shown by the electrical analogy discussed above, a flat frequency transmission characteristic may be obtained by connecting the driving force to a mechanical transmission line which comprises a plurality of sections, each consisting of a series inductance and a shunt capacity providing these inductances and capacities have proper values and providing a large number of sections are employed. In case it becomes desirable to employ only a small number of sections, such as only one or two, the flat frequency transmission characteristic may still be substantially obtained by terminating the one or two sections of the network at mid-shunt, for example, with an impedance equal to the impedance of an infinite number of sections of the same type. The masses and elasticities of the armature and the plunger

or diaphragm make up the two sections of the artificial line employed, and by coupling the armature and the diaphragm to a horn having an impedance approximating the impedance of a mechanical transmission line; comprising an infinite number of sections of series mass and shunt elasticities of values corresponding to those of a full mechanical section, determined by the masses and elasticities the same flat transmission characteristic may still be obtained.

Fig. 15 illustrates the mechanical diagram of the arrangement of Fig. 14 in which element 87 is the driving force which has connected thereto a series mass or inductance 89, corresponding to the mass of the armature, a shunt capacity or elasticity 90 corresponding to the elasticity of the reed 85, an inductance or mass 95 corresponding to the plunger 81, a shunt capacity or elasticity 92 corresponding to the elasticity of the air chamber 83, and a resistance 93 corresponding to the resistance of the horn 82. The element 91 is not intended to indicate an actual mass or inductance but rather that there is a transformer action at this point. Looking in the two directions from this point, the impedances differ and the areas working into the common elasticity 92 have a ratio equal to the square root of the impedances in the two directions. At this point lines of different impedances are coupled together without reflection losses as in the case of the usual type of transformer. Hence element 91 has been included in the electrical diagram to indicate this effect.

Fig. 16 illustrates the present invention embodied in a public address system for obtaining a large increase in volume of the voice of a speaker, for example. The system briefly comprises a telephone transmitter 100 working into a 4-stage amplifier, the output of which is coupled to a plurality of loud speaking telephone receivers having horns arranged to direct the amplified sound waves in the desired direction or directions.

The 4-stage amplifier comprises three vacuum tubes, 101, 102, and 103, in the first three stages, each of these tubes being essentially a voltage amplifier, in order to produce a high voltage amplification of the speech frequency currents impressed upon the amplifier from transmitter 100. The fourth stage is essentially a current amplifier, and comprises two parallel connected tubes, 104 and 105, connected in push-pull relation with two other parallel connected tubes, 106 and 107. Space current for tubes 101, 102 and 103 is supplied from a common source of voltage, 109. The filaments of these three tubes are heated by current from a source of voltage 108. In order to obtain the desired negative grid potential for tubes 101 and 102, it will generally be found sufficient to insert small resistances, 110 and 111, in a path common to the grid circuit and the heating circuit for each tube, whereby each grid is maintained at a negative potential with respect to its cathode by the I R drop in the common resistance. Tube 103, being in the third stage of the amplifier, will generally require a considerably higher grid potential, and this higher grid potential may be obtained by a separate grid battery, 112, of the desired voltage. Space current for tubes 104 to 107 is supplied from a source of voltage 124 which may have a voltage as high as 750 volts or higher in case high powered tubes are employed. The filaments are heated by an alternating current source 125 through a transformer 126.

Transmitter 100 is coupled to the input circuit of tube 101 by a step-up transformer, 113, which has its secondary winding shunted by the high resistance 114. The impedance ratio of transformer 113 should be so adjusted with respect to the internal impedance of tube 101 and the value of resistance 114 that the impedance of the input circuit of the tube, as seen from the terminals of the primary winding of transformer 113, is of substantially the same value as the impedance of the transmitter circuit looking towards the transmitter. Tubes 101 and 102 are coupled by a shunt retardation coil 117, a series condenser 115, and a shunt high resistance 116, the drop across a portion of this resistance being impressed upon tube 102. Due to the fact that voltage amplification is desired by tubes 101 and 102 the output circuit impedance of tube 101 may be considerably greater than the internal impedance. For example, the internal impedance of tube 101 may be 80,000 ohms while resistance 116 may be 500,000 ohms. This will cause some loss in energy transfer but will enable a much higher voltage amplification to be produced. This sacrifice in energy however will not be accompanied by any loss in quality since the higher the impedance into which a tube works the better will be the quality although from the energy standpoint the optimum is reached when the internal and external impedances are ~~matched~~ *equal*.

The output of tube 102 is similarly connected to tube 103 by a shunt retardation coil 118, series condenser 119 and shunt resistance 120, and resistance 120

may also have a value of 500,000 ohms in case tube 102 has an internal impedance of 80,000 ohms in order to enable high voltage amplification to be obtained. The output of tube 103 by a transformer 121 is coupled to the current amplifier tubes, and a resistance 122 is connected across the secondary winding of this transformer, whereby the combined resistance and transformer impedance ratio may be adjusted to enable tube 103 to work into its own impedance or a still higher impedance. The cathodes of tubes 104 to 107 are connected to the midpoint of this resistance. The output circuits of tubes 104 to 107 are coupled to a plurality of loud speaking receivers 128, by a suitable transformer 127. In order that the volume of sound delivered by each loud speaking telephone receiver 128 may be adjusted to suit any particular conditions, an auto-transformer winding, 129, is shunted across the secondary winding of transformer 127 and the various loud-speaking receivers may be connected to any desired point on this auto-transformer, due to the provision of a plurality of tap out points along its length. Since these four tubes are current amplifiers it will be desirable to have a maximum transfer of energy from the tubes to the receivers and this will be obtained when the tubes work into an impedance equal to their combined impedance. Transformer 127 and the auto-transformer 129 should therefore be so adjusted with respect to the impedance of the receivers that tubes 104 to 107 work into approximately their own impedance, which external impedance will not be substantially changed with variations of the receiver settings on the auto-transformer.

If now the mechanical impedance of the loud speaking receivers is made to match the mechanical impedance of the associated horns, it follows that this system just described will enable sound waves impressed upon transmitter 100 to be changed into alternating currents amplified in voltage by tubes 101, 102, and 103, amplified in current by tubes 104 to 107, and converted into sound waves of large volume by the loud speaking receivers without distortion of the original sound waves impressed upon the transmitter. This absence of any appreciable distortion is due to the matching of electrical impedances between the transmitter and the first amplifier, the working of each amplifier tube except the last into a great impedance, the matching of electrical impedances between the output of the last amplifier and the loud speaking receivers, and the matching of mechanical impedances between each receiver and the associated horn. Each of the horns employed with the receivers may, for example, have a substantially constant impedance over the essential speech or music frequency range.

The matching of mechanical impedances, as described above, is, of course, of wide application, and not limited to the matching of mechanical impedances between a horn and a diaphragm or plunger which is electrically operated, since the method described for obtaining this matching is independent of whether or not the driving force is mechanical or electrical. It is, therefore, obvious that the above matching of impedances may be employed in such systems as phonographs and the like, in which the diaphragm or plunger which actuates the air contained in the associated horn, is driven by a sound record needle or other mechanical force. Various other modifications of this invention may be made, as will appear to those skilled in the art, without departing in any wise from the spirit of this invention as defined in the appended claims. In particular this invention is not limited in its use to a system employing a tapered horn since other sound radiating means may be employed such for example, as a radiating member comprising two conical surfaces with their large ends coupled together and composed of paper or other flexible material, the apex of one of the cones being connected to the vibrating armature and reed or other driving force. The masses and elasticities of such a system may be arranged with the proper values to give a mechanical transmission line of substantially constant impedance over a wide frequency range.

Having now particularly described and ascertained the nature of our said invention and in what manner the same is to be performed, we declare that what we claim is:—

1. Method of reducing the distortion in an acoustic device comprising an air chamber located between the vibrating member and one end of a tapered horn which consists in adjusting the dimensions of the chamber so that the opposition to mechanical vibratory energy flow due to the combined effect of the mass of the members and the elasticity of the air in the chamber is of the same order of magnitude as the opposition to mechanical vibratory energy flow of the air in the horn.

2. A sound reproducing device in which a member is adapted to vibrate either mechanically or electrically and to

vibrate indirectly, by means of an intermediate vibratable coupling, a column of air and in which the ratios of the elasticities to the masses of the said member, coupling and air column are constant over a wide frequency range.

3. A sound reproducing device in which a fluid coupling is disposed between a vibrating diaphragm and the horn and in which the ratios of the elasticity to the mass of the coupling fluid would be such that the opposition to mechanical vibratory energy flow would be constant over a wide range of frequencies.

4. An acoustic device in which a member is located at one end of a horn having a substantially constant opposition to mechanical vibratory energy flow and subjected to mechanical vibrations for vibrating the air in the horn and in which an air chamber is provided located between said member and the adjacent end of said horn of sufficient size to cause the shunt elasticity resulting therefrom in combination with the mass of said member to present to the horn a mechanical impedance of the same order of magnitude as the mechanical impedance of the horn over a wide frequency range.

5. An acoustic device in which an air chamber is located between a vibratable member and one end of a horn, having a substantially constant opposition to mechanical vibratory energy flow over a wide frequency range and in which the dimensions of the air chamber are such that the opposition due to the combined effect of the shunt elasticity resulting from the chamber and of the mass of the member are equal to the opposition due to the air in the horn.

6. A sound reproducing device substantially as described in connection with the accompanying drawings.

Dated this 6th day of October, 1923.

WESTERN ELECTRIC COMPANY LTD.,
By F. T. Woodward,
Their Attorney.

Abingdon: Printed for His Majesty's Stationery Office, by Burgess & Son.
[Wt. 95A.—125/8/1932.]

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Fig. 1.

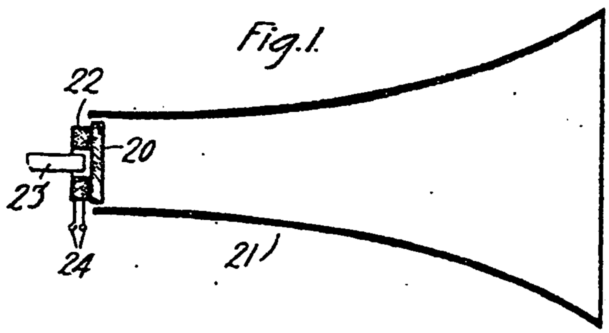
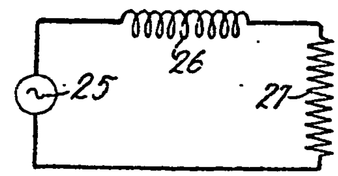
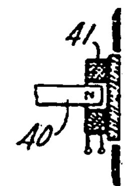


Fig. 2.





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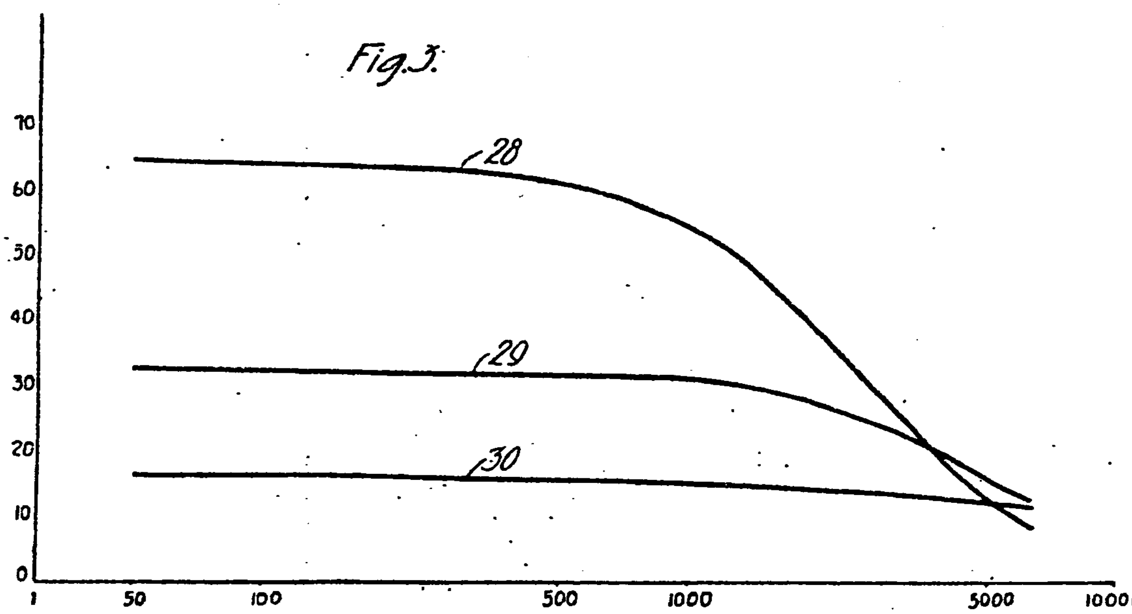

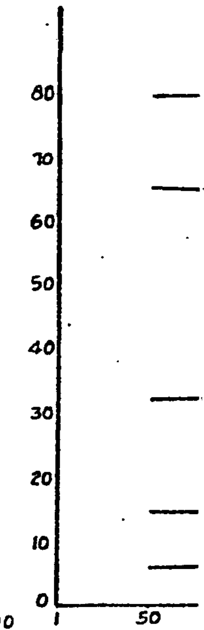

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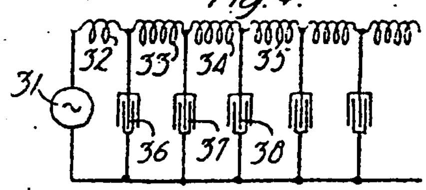
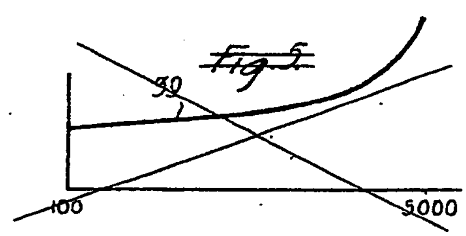
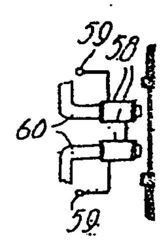


~~Fig. 5.~~





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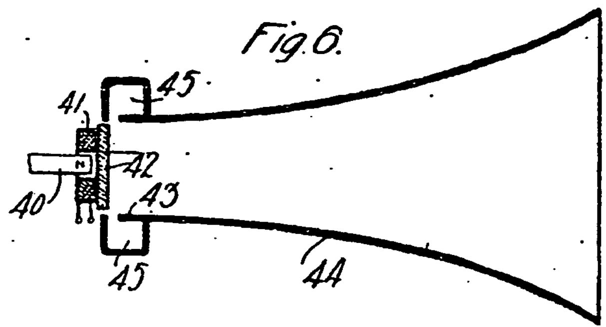

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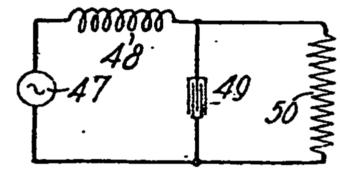
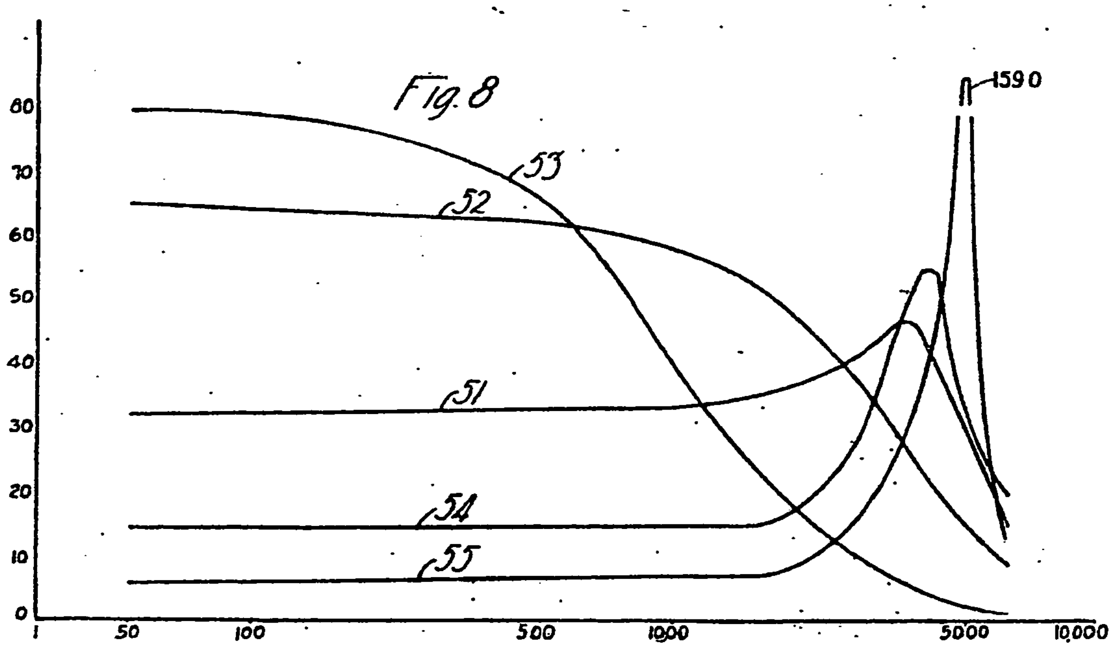


Fig.8



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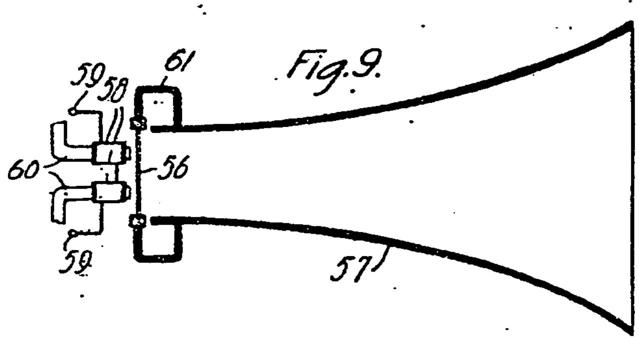

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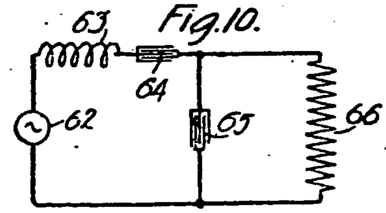

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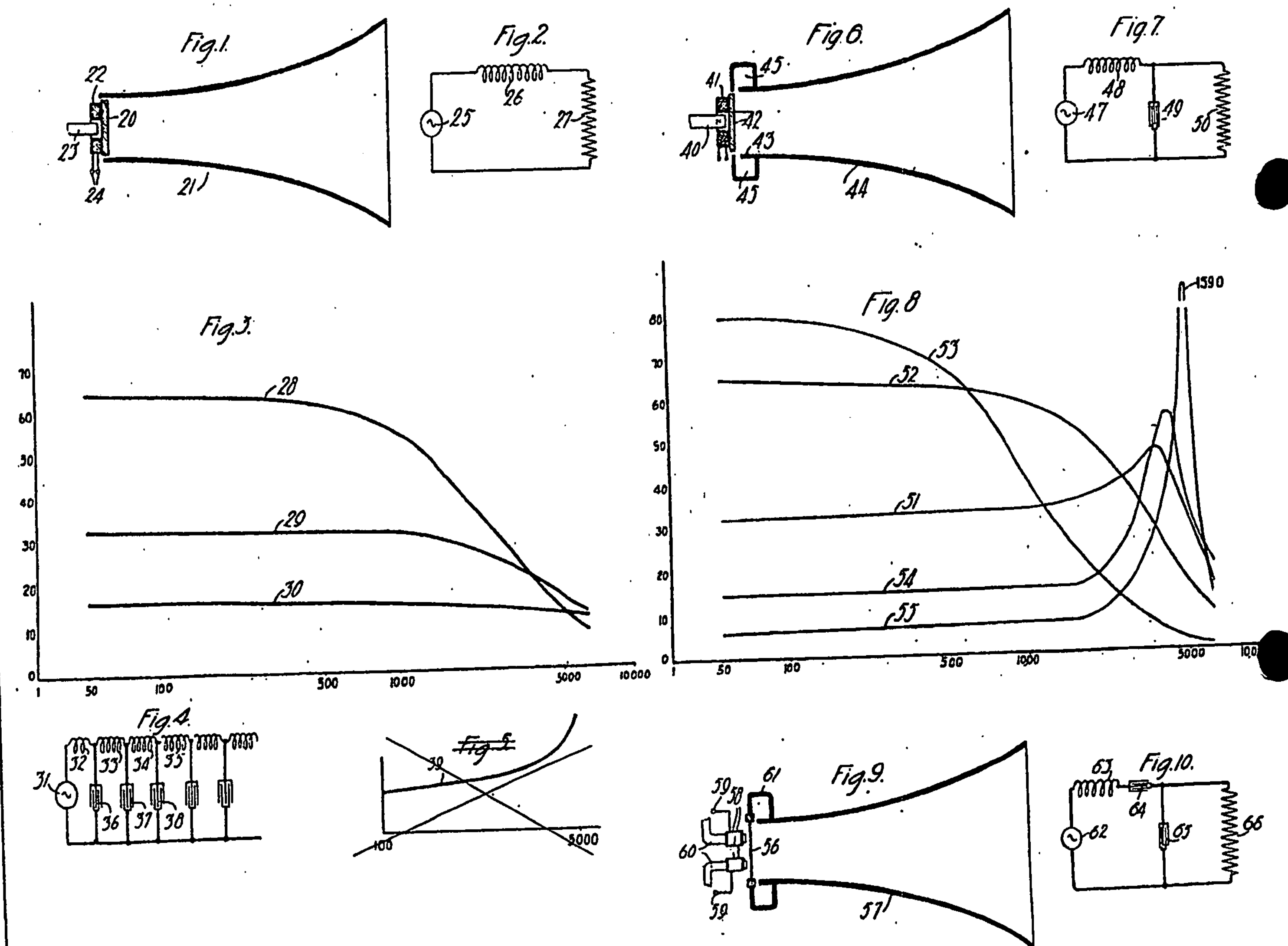

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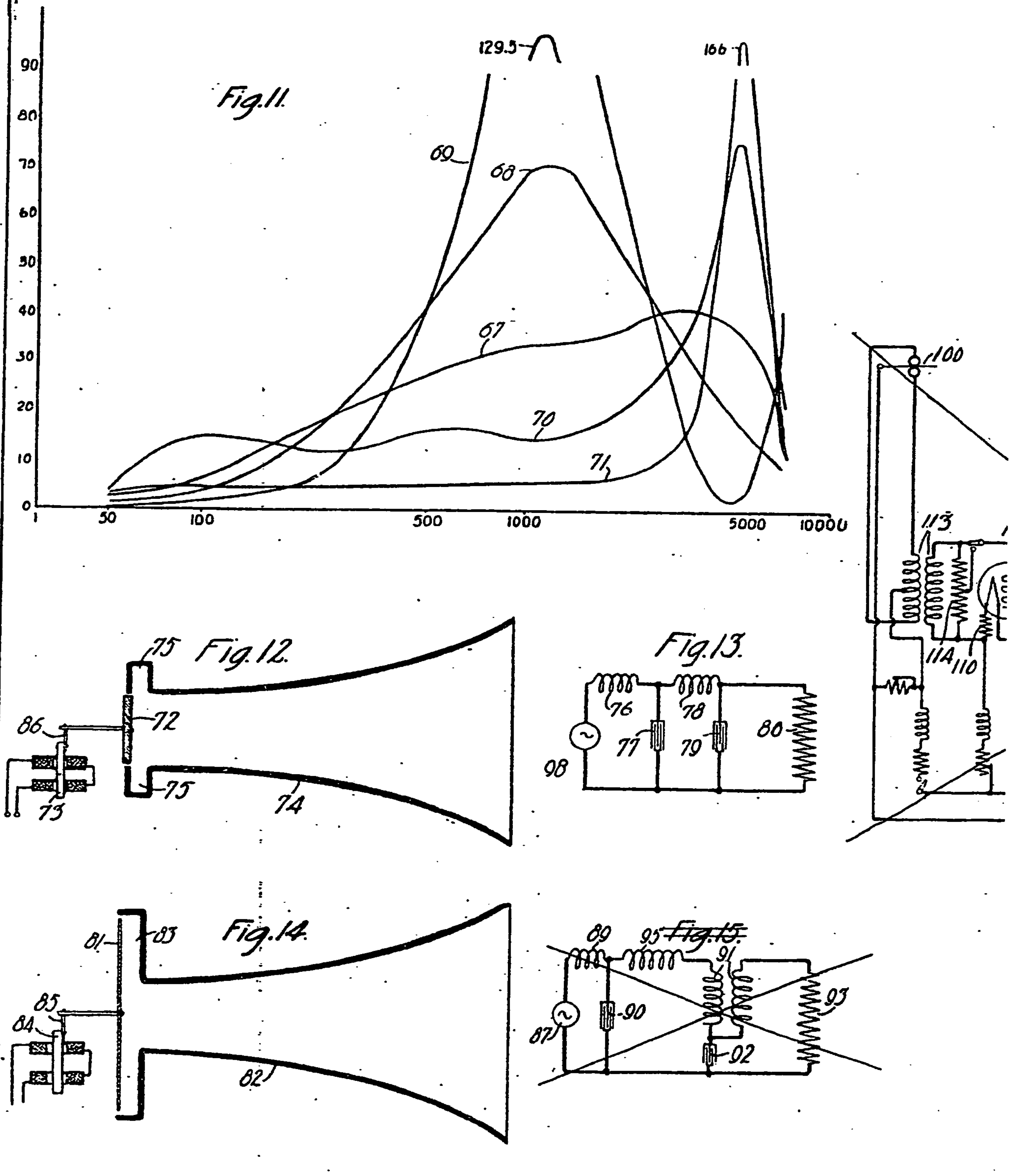
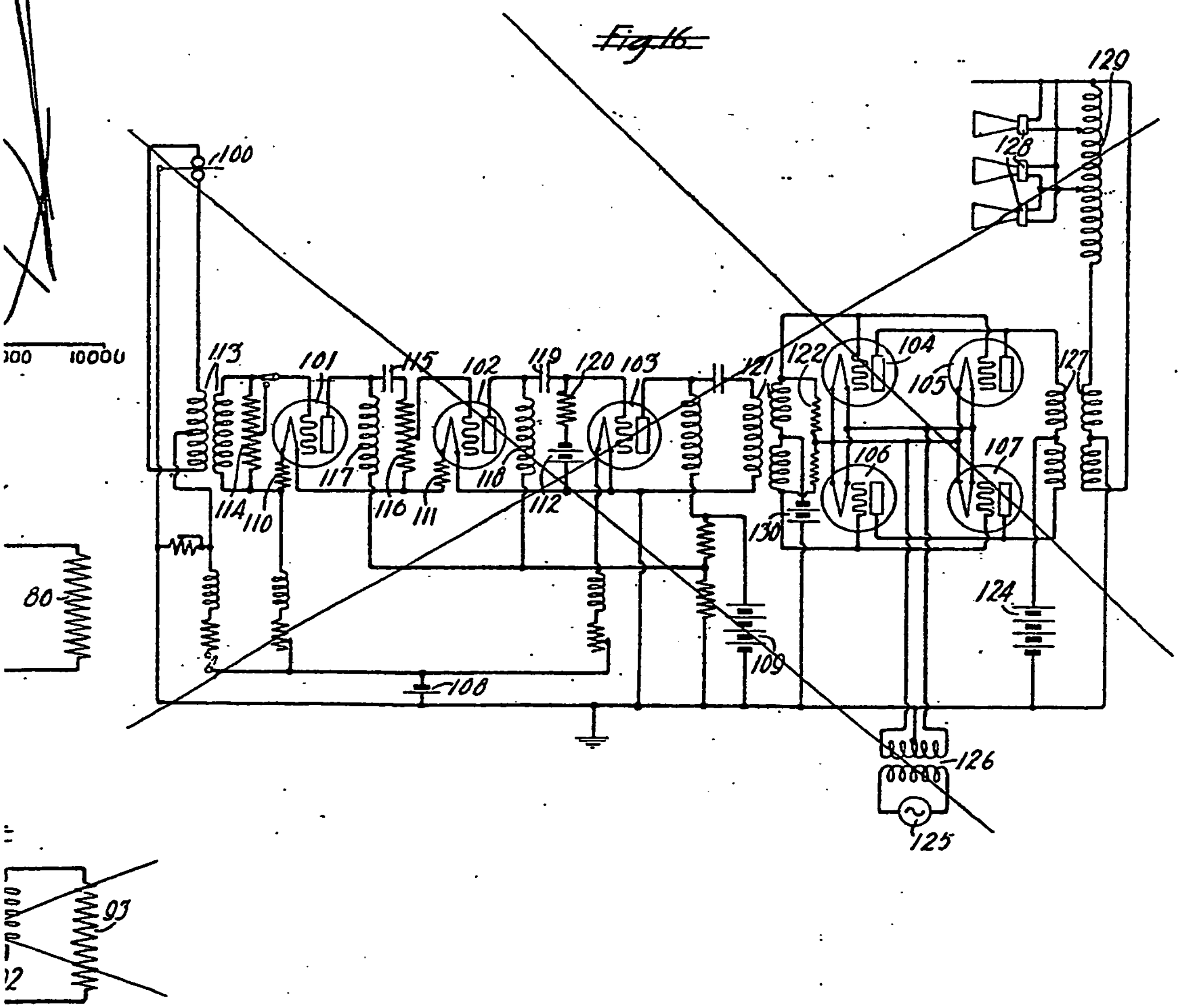


Fig.16.



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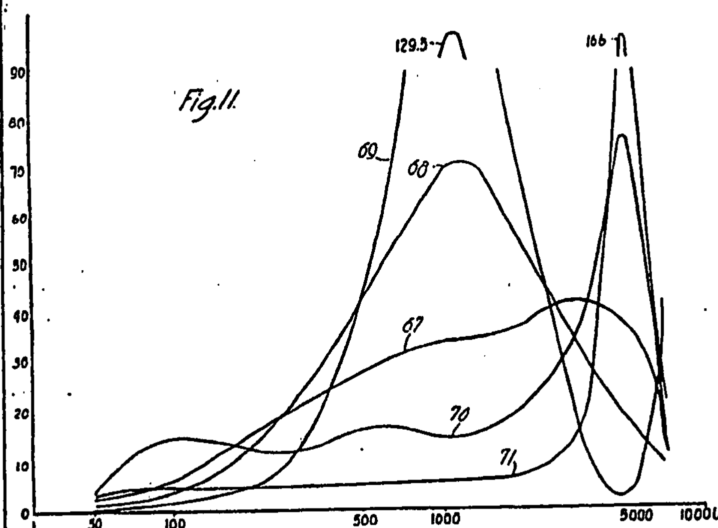

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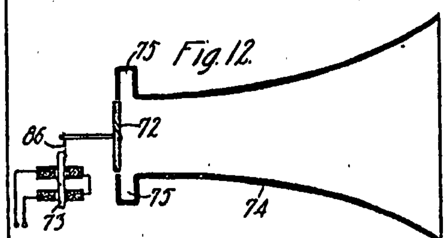

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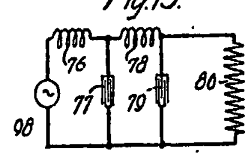

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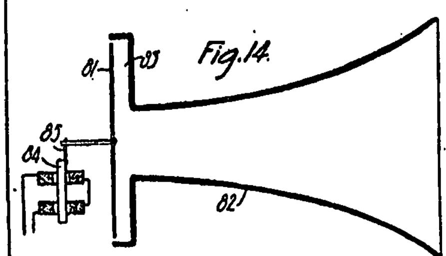

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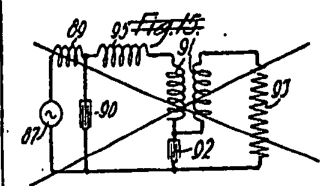

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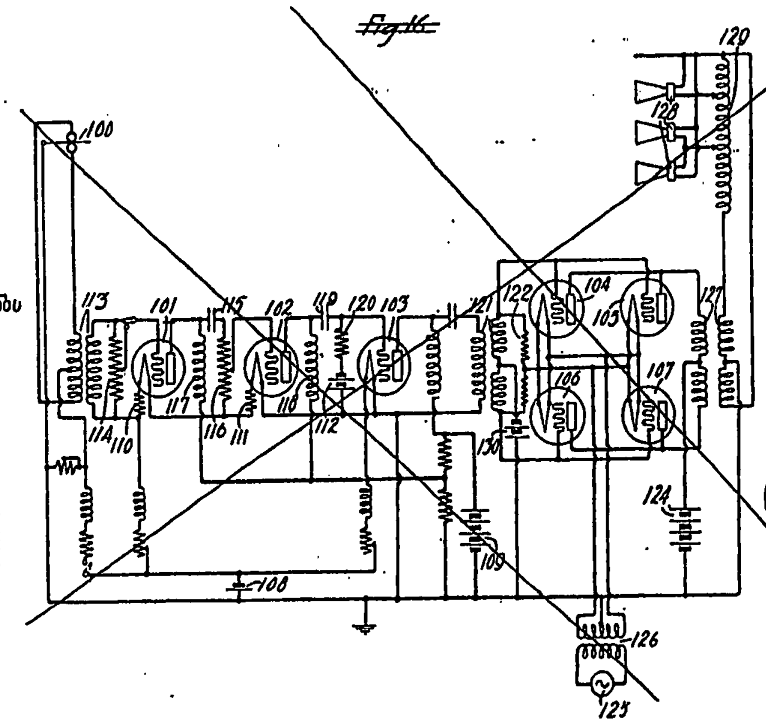

Fig. 16.

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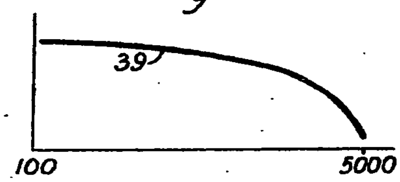
Fig. 5.



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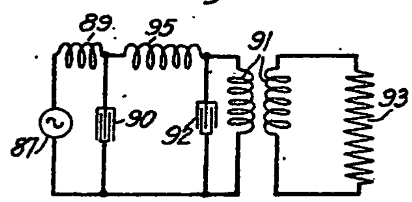

Fig. 16.